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BEARING ARRANGEMENT

The present invention relates to a bearing arrangement, particularly but not exclusively in the field of precision bearings for example for measurement apparatus having articulated wrist parts.

Precision bearings of many forms are known. The simplest rely on the sliding contact to transfer loadings. More complicated bearings have rolling contact, for example ball race or roller sets. Rolling contact is preferred for high loadings, high rotational speeds and long bearing life. However these bearings need to be manufactured in an accurate manner and are consequently expensive. Where thin section parts are used they tend to take up the shape of the housing to which they are fitted. As a consequence, their housings too must be accurately made if good accuracy of movement is to be maintained.

Sliding contact bearings may be used for precision bearings, for example watch bearings. Watch bearings, and similar, are lightly loaded and so do not need large bearing surfaces to transfer forces. Typically a rotatable shaft might have conical ends and be held in place between two plates with complementary end accepting parts. This type of bearing, although simple and low cost, is difficult to adjust when wear takes place. Wear being more common where sliding contact is employed.

One commercially available bearing, used typically for roundness measurement machines provides a fixed block, e.g. of P.T.F.E., having a conical recess and a ball

seated rotatably within the recess. Again wear adjustment for such a bearing is problematic and the arrangement is not used in pairs.

According to one aspect of the present invention there is provided a bearing arrangement comprising:

two bearing assemblies each located on an axis;

each bearing assembly comprising two parts in contact during their relative rotation;

at each assembly the contact taking place in a plane;

one of the assemblies allowing resilient displacement of its contact plane and the other of the assemblies being relatively rigid for preventing substantial displacement of its contact plane.

Another well-known bearing is a ball joint. Typically a spherical part is held in a complementary socket for movement with more than one degree of freedom. An example of such a joint is shown in Figs 8 and 9 of European Patent No. 680599 (Renishaw) see balls 80 and triangular socket 78.

Each of the sockets 78 is formed in a leg 77 which is resiliently movable. This means that tube 72 supported between two legs 77 may be displaced resiliently back and forth. In so doing these legs alter the position of the rotational axis of the tube 72.

According to a second aspect of the invention there is provided a bearing arrangement comprising:

two bearing assemblies each located on an axis;

each bearing assembly comprising two parts in contact during their relative rotation;

at each assembly the contact taking place in a plane;

at least one of the assemblies allowing resilient displacement of its contact plane in a direction parallel to the axis.

The shortcomings mentioned above are particularly noticeable when such bearings are used for rotation (including pivoting) of elements of measuring equipment. In such equipment exact repeatable circular motion is necessary even after bearing wear or thermal changes in dimensions of component parts, and lightness and low cost are desirable.

According to a third aspect of the invention there is provided measurement apparatus having a pivot including a bearing arrangement according to the first or second aspect of the invention. Preferably the measurement apparatus includes a mechanical wrist element.

Preferred features of the invention according to the first, second or third aspects are given in the subsequent paragraphs.

The two parts of each of the bearing assemblies may include a female part having a recess or aperture and a male part acceptable into the recess or aperture.

The contact may be sliding contact.

Where there is sliding contact this contact may be between the female and the male parts of at least one of the bearing assemblies and may be at discrete locations in the plane.

The discrete locations may be provided by a non-circular recess or aperture (e.g. triangular or trihedral) in the female part co-operating with a circular (for example spheroidal or conical) male part, or may be provided by a circular (e.g. conical or straight-sided) recess or aperture in the female part co-operating with a non-circular (e.g. trihedral) male part.

Alternatively the contact may be rolling and the parts may include a ball race.

The movement of the plane may be provided by a movable female part and where the movement is resilient the female part may be resiliently movable. Possibly the female part is a planar support having spring qualities.

Associated with each assembly may be first and second relatively rotatable housings. The female and male parts of each assembly may be associated with either of the first and second housings.

According to a fourth aspect of the invention there is provided a support for a measurement probe comprising an articulatable wrist providing two axes of rotation for the probe, at a first axis there being provided a bearing arrangement as claimed in any one of claims 1 to 10, the bearing arrangement being connected to a spindle having an extension extending beyond the bearing arrangement in the direction of the first axis.

The invention is described hereinafter with reference to measurement apparatus for use on a coordinate

measuring machine (CMM). However, this is an example of one possible application and is not intended to limit the invention in any way. The invention could be applied to any apparatus where relative rotation of parts is required e.g. a rotatable support for optical components which require accurate rotation possibly of the type described in UK Patent Application No. GB 0019199.9.

The invention will now be described with reference to the drawings, wherein:

Fig 1 shows a probe, and an articulatable probe wrist employing the invention;

Fig 2 shows a detail of a component shown in Fig 1;

Fig 3 shows a sectional view through line III-III in Fig 2;

Fig 4 shows a further detail of a part of a component shown in Fig 1;

Fig 5 shows an alternative arrangement of some of the parts shown in Fig 1;

Figs 6A-6F show various configurations of bearing arrangements according to the invention;

Fig 7 shows yet another alternative arrangement of some of the parts shown in Fig 1; and

Figs 8 to 11 show alternatives to some of the parts shown in Fig 1.

Referring to Fig 1 there is shown a probe 2 having a stylus 4 for contact with an item to be measured. Conventionally, in use, the quill 8 of a CMM will be moved in any of the three orthogonal axes until the stylus 4 touches an item. The position of the quill 8 with respect to the three axes is then used to

determine dimensions of the item.

In addition to the three axes, a probe head 6, attached to the quill 8 between the quill and the probe has a wrist configuration which adds two rotational axes of movement to the probe - rotation "A" in a vertical plane and rotation "B" in a horizontal plane. Motors M_A and M_B provide the torque for the rotation in the two axes, so measurements may be taken with or without moving the quill 8, by moving the probe head 6.

Articulation of the head allows more complex movements of the probe, for example to measure the roundness of a bore along its length by moving the stylus in a helical path around the bore. The position of the stylus can be calculated from the known rotational position of the stylus and the three CMM axis readings.

Such rotational movement of the probe requires accurate and repeatable movement of the bearings in the probe head. In this embodiment the probe is mounted to a carriage 14 held on a horizontal spindle 16. The spindle 16 has a bearing assembly at each end connected to a lower housing 12 of head 6. The lower housing 12 is connected to a vertical spindle 18 in an upper housing 10 of the head 6 which has two bearing assemblies also.

Horizontal spindle 16 may rotate relative to the lower housing 12. Rotation is achieved by use of two bearing assemblies having parts 20 and 28, and 22 and 29. Male bearing parts in the form of balls 20 and 22 are fixed (for example by means of adhesive) to the ends of the spindle 16. Each ball is accommodated in a female part

in the form of supports 28 and 29 each having male part accepting apertures therein such that the spindle's only possible movement is rotation "A". Similarly lower housing 12 is rotatably mounted via vertical spindle 18. Two bearing assemblies are shown comprising male parts in the form of two balls 24 and 26 accommodated in two female parts in the form of supports 30 and 32 having apertures therein, all providing rotational movement "B".

Balls 20,22,24 and 26 can be manufactured by known techniques to very high accuracy, i.e. less than 0.16 microns overall roundness tolerance. This exact sphericity provides accurate movement of the probe in rotation. The balls may be of a ceramic, ruby or steel material.

Each spindle 16 and 18 has a fixed support i.e. 29 and 30 respectively and a movable support i.e. 28 and 32. The fixed support is held in fixed relation to its mounting whereas the movable support can move resiliently in the direction of the associated rotational axis.

Power and signal paths a,b,c,d and e are shown. Path a provides power to motor M_A for rotating spindle 16 (and hence probe 2) about axis A. In practice this rotation will be pivoting motion in an arc of up to 180°. Path b provides power to motor M_B for rotating spindle 18 (and hence lower housing 12 and probe 2) about axis B. In practice this rotation can be continuous so arcuate pivoting back and forth is not necessary.

The rotational position of spindles 16 and 18 can be

determined by rotary encoders 86 and 88 respectively. Paths e and c are provided for the encoder signals.

Paths a,d and e have a rotary coupling 90, the two halves of which may be in sliding contact (e.g. by use of slip rings) or may be of the non-contact type (e.g. a capacitive, inductive, infra-red, optical or R.F. link). The rotary coupling allows continuous rotation of the lower housing 12 relative to the upper housing 10.

Fig 2 shows the form of the supports 28 and 29. Holes 34 for mounting screws are shown, as is a central triangular aperture 40 for receiving a ball 20 or 22. In order that the support 28 be resiliently movable it is formed from sheet, for example steel material or other planar material with inherent resilient spring-like qualities. Support 28 is arranged to be deflectable under load, although, as described below, may be preloaded at assembly also.

For simplification of manufacture support 29 can be identical to support 28 but mounted rigidly (as illustrated) or a thicker material can be used. Alternatively support 29 might be integral with the lower housing 12.

In this design three ball contacting areas 36 are formed on the three sides of the aperture 40. These areas are formed with a curved surface having a radius larger than the radius of the ball 20 or 22. Areas 38 do not contact the ball. The contacting areas are formed by forcing a ball, of slightly larger diameter than the bearing ball 20, into the triangular recess.

The recesses may be coated with friction reducing material. The balls may be coated with friction reducing material also, but may lose some of their sphericity in the process, so this step is not favoured.

Fig 3 is a section along line III-III in Fig 2. In this drawing the support 28 is shown in a loaded condition. In this condition support 28 is deflected and each area 36 will have moved from an unloaded condition by the same amount relative to the axis of rotation. It will be noted that the curvature of the surface of each area 36 provides a contact point 42. In order to make this contact point lie in the middle of area 36, the surface is formed with its radius when the support 28 is loaded. A load may be applied to the support during assembly as a preload.

A cone generated by the revolution of a line between the centre of the ball 20 and its points of contact 42 with the support 28 will have a cone angle θ. This angle θ is chosen to minimise rotational friction, to maintain bearing radial stiffness and to inhibit dislodgement of the ball. Any angle between 20° and 175° can be used but an angle of about 80° has been found to be suitable.

The ball contacting areas 36 may be formed by forcing a cone into a support rather than a ball, to produce partially conical contact areas 36. In this instance, point contact will be achieved also.

Fig 4 shows a detail of a fixed support 29. This support may be manufactured in a slightly different

manner to the support 28 shown in Fig 3. Support 29 is not deflected in use but is held comparatively rigidly by lower housing 12. The contact surface 36 is again formed with a slightly larger radius than the radius of the ball but the support is not deflected whilst the radius is formed. The cone angle θ may be approximately the same as the angle θ formed at support 28.

Referring back to Fig 1, spindle 18 is mounted between supports 30 and 32. An extension 19 of the spindle 18 carries the lower housing 12. The principles of construction of the balls 24,26 and their supports 30,32 are the same as those described above for the balls 20,22 and their supports 28,29. However, ball 24 is larger than the others because it carries the weight of the lower housing 12 and so requires greater stiffness, also it has to accommodate spindle extension 19. In this arrangement support 30 is fixed and support 32 is deflectable. Support 32 will be preloaded in the manner described above. The cone angles will be similar. Use of extension 19 through bearing 24/30 together with the rotary coupling 90 allows continuous rotations of lower housing 12 and its associated parts.

The configuration of spindle 18 and supports 30 and 32 provides tolerance to thermal effects because the lower end of the CMM quill 8 is close to the plane in which support 30 and ball 24 have contact. Thus thermal growth of housing 10 does not alter significantly the position of housing 12 because there is little material in the width between the base of the CMM quill and the said plane.

This means that any changes in dimension of upper housing 10 due to thermal effects will not alter substantially the position of the stylus 4.

An alternative bearing arrangement for upper housing 10 is shown in Fig 5. This arrangement has a fixed support 30 at the top and the deflectable support 32 below.

Figs 6A-6F show examples of some permutations of ball and support configuration. For ease of identification the fixed supports have been referenced as 50, deflectable supports 55, and relatively rotatable parts 60 and 65. All these permutations fall within the ambit of the invention.

Fig 7 shows another, alternative arrangement of bearing parts. In this arrangement balls 20 and 22 are each supported in ball race bearings 80. The races 80 are in turn held in supports 28' and 29'. As discussed above support 28' allows some axial movement, and support 29' is relatively rigid. A preload is applied to the supports and balls as discussed above. Use of ball races 80 reduces friction. The supports 28' and 29' need not have triangular holes, holding the ball races 80 in place.

The reference numerals used in Fig 7 relate to the horizontal axis shown in Fig 1, however, a similar "ball raced" construction may be employed also for the vertical axis bearings of the embodiment shown in Fig 1.

An alternative construction of the ball and support

contact area is shown in Fig 8. In this embodiment support 28,29,30,32 is flanged to accommodate ball 20,22,24,26. The ball rests on an annular low friction collar 82 which may be manufactured from P.T.F.E., a ceramic or a similar low friction material. The collar may be replaced with three pads of a similar material. In either case the collar or pads may be fixed with adhesive to the support.

Yet another alternative construction of the ball and support contact area is shown in Fig 9. In this embodiment support 28,29,30,32 has adhered thereon a block of elastically deformable material e.g. P.T.F.E. or other low friction plastics material or an oil impregnated sintered product having a conical recess therein. The recess accommodates ball 20,22,24,26. The elastic properties of the material of the block takes up slight deviations in the roundness of the ball so that the relative rotation of the block and ball has greater circular accuracy than the circular accuracy of the ball alone.

Further embodiments of the ball and support construction are shown in Figs 10 and 11. In each of the Figures ball 20,22,24,26 is supported in a plastics insert 85 of P.T.F.E. or the like supported within an outer collar 90. The ball of Fig 10 is supported in a cylindrical recess 92 and the ball of Fig 11 is supported in a conical recess 94. Again the plastics insert will, under load, deform elastically to the shape of the ball and during relative rotation take up any out-of-roundness of the ball to give accurate circular motion.

Various modifications and enhancements will be apparent to the skilled addressee. For example whilst spherical bearings and triangular apertures are illustrated, within the ambit of the invention, any configuration of sliding contact between male and female parts is possible providing contact is made in a plane. It is possible that this plane, whilst it will be perpendicular to the axis of rotation in the illustrated embodiments, may not be so e.g. if supports 28 and 29 say lie in planes offset to the perpendicular and balls 20 and 22 are used.

So the supports illustrated may, according to the invention, be simply a recess e.g. a circular hole, a conical recess, a trihedral recess, a multi-sided hole, or the like, perhaps formed directly into a housing 12 or 10, or in the form of an insert in a sprung plate. A support might be formed also in a spindle 16 or 18, in which case a male part would be connected to the housing 10 or 12.

The male part may be any shape e.g. spheroidal, elliptical, conical, trihedral, or polygonal. If the male part is non-circular then the support must be circular, and vice versa. Where the support or male part is non-circular then contact at discrete points between the two is made, these points will lie on a plane also.

The male/female parts of each bearing assembly may differ in construction.

Whilst the discrete locations at which the balls make sliding contact with the supports are illustrated as

sides of an aperture, they may be the sides of a recess, e.g. a low friction insert having a faceted recess in a support. Contact might be provided at the edges of an aperture or recess.

Also the spindles 16 and 18 may be constrained against excessive movement away from their axes of rotation such that should the spindle be forced out of register with a support it would be pushed back into register by virtue of the resilient nature of one of the supports.

The embodiments described above have certain advantages over the prior art. In particular, the embodiments allow wear and/or changes in dimensions of the component parts mentioned to be accommodated without significant loss in accuracy or repeatability, i.e. change in position of the stylus.

For example a change in the dimension between balls 20 and 22 can be accommodated by resilient movement of support 28. This movement causes all points of contact between support 28 and ball 20 to move along the axis A by the same amount and therefore the position of the axis A does not change as a result of the resilient movement. Whilst the stylus may move slightly parallel to the axis A, its movement will be small in comparison to the change in dimension between the walls 20 and 22 (approximately half).

Positional stability of the stylus is achieved also by the provision of a fixed support 29. The fixed support provides positive positioning of the spindle 16 at one position on the axis A.

The same advantages are gained by the configuration of the bearings 30/24 and 32/26 in the upper housing 10. Likewise the permutations shown in Figs 6A-F have the advantages mentioned in the preceding paragraph.